Development of the surface reflectance Fundamental Climate Data Record from the Landsat archive, the LDCM mission and future Landsats

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Objectives

- to provide an algorithm and code for a Surface Reflectance Standard Product for integration into the LDCM processing system.
- prior to LDCM launch, to test the proposed approach using similar dataset (Formosat-2)
- to validate the resulting LDCM product, using data from AERONET
- to provide a cloud masking and cloud shadow screening algorithm for LDCM
- to undertake vicarious calibration of the LDCM instrument
- to advise on and contribute to the LDCM program outreach and explore the potential synergy with other high resolution international earth observation programs (e.g. through the LCLUC, GLAM GOFC/GOLD and IGOL programs).
- to be an active contributor to the LDCM Team, participating in telecons, science team meetings and working groups as appropriate.

Basis/Rationale for the Landsat Surface Reflectance Product

- The Surface Reflectance standard product developed for MODIS provides the basis for a number of higher order land products for global change and applications research
- The fully automated and robust approach used for MODIS has been adapted for Landsat missions
- The code (LEDAPS variation) has been made available to a large community of users and could be delivered to LDCM ground stations.
- Higher order products (LAI/FPAR, Forest Cover Change, Automatic First Stage Classification) have been already generated from SR products.
- Validation/Evaluation plan is clearly defined and underway (AERONET)
- Automatic Quality Assesment and accuracy verification is also achieved (GFCC project)
- Improvements have been implemented (or are underway) in optimized version of the original code (WELD, Google Earth Engine) in particular with aerosol model and use of lookup tables

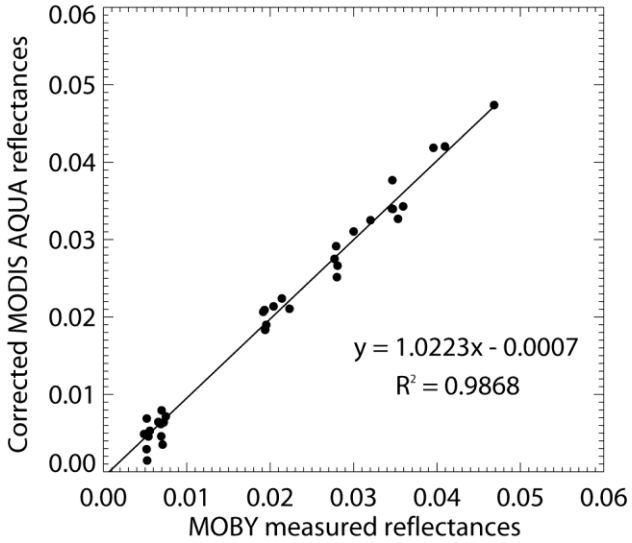
Approach for the surface reflectance product

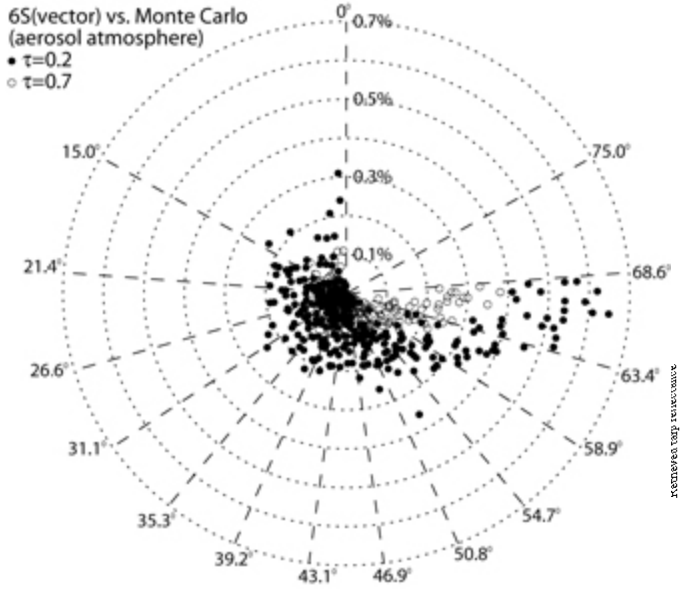
- **Atmospheric correction consistent with the MODIS, AVHRR and VIIRS approach, ensuring consistent reflectance data across resolutions based on rigorous radiative transfer**

  http://6s.ltdri.org

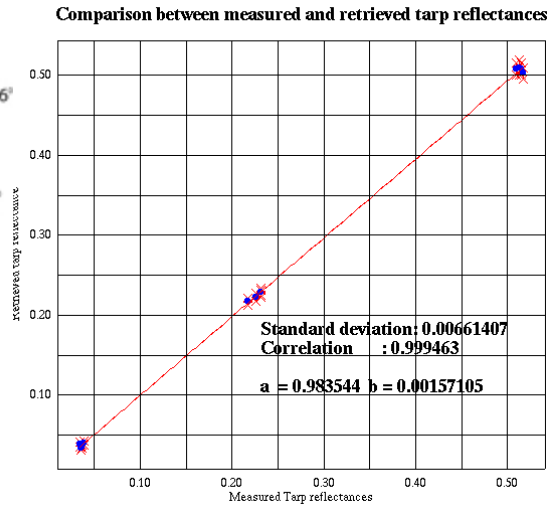
  http://rtcodes.ltdri.org/

MODIS AQUA vs MOBY





IKONOS vs TARP

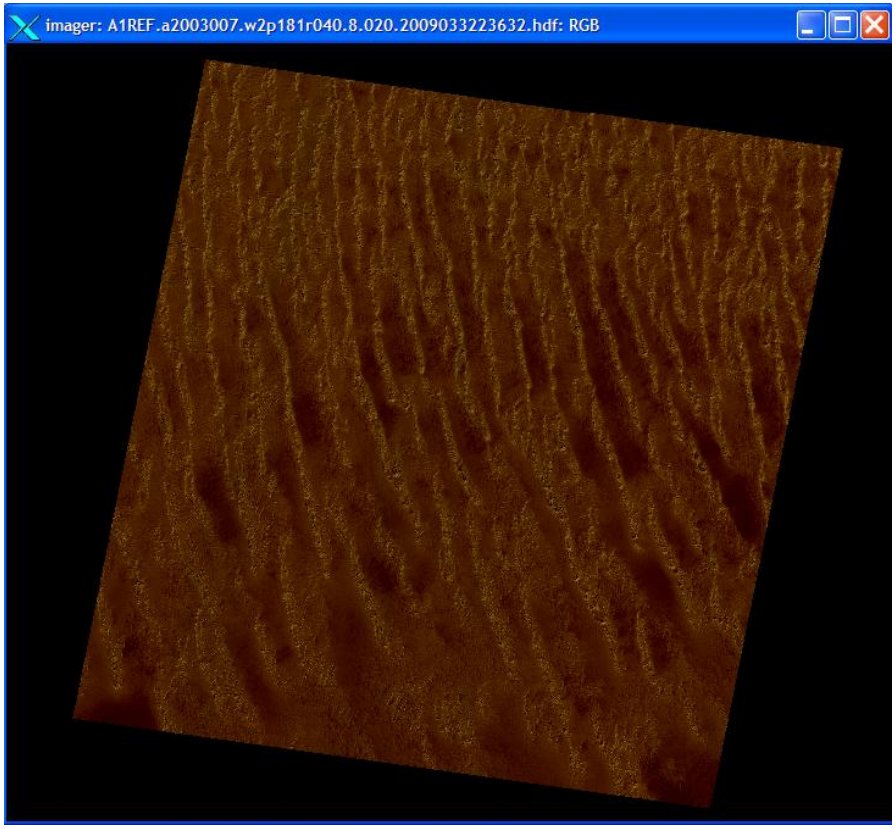


Calibration

- MODIS calibration accuracy at ~2%, methods have been developed to cross-calibrate other instruments.
  - MODIS/Terra & ASTER: Simultaneous Nadir Observation
  - VIIRS & MODIS/Aqua: Near simultaneous, (BRDF corrected surface reflectance comparison)

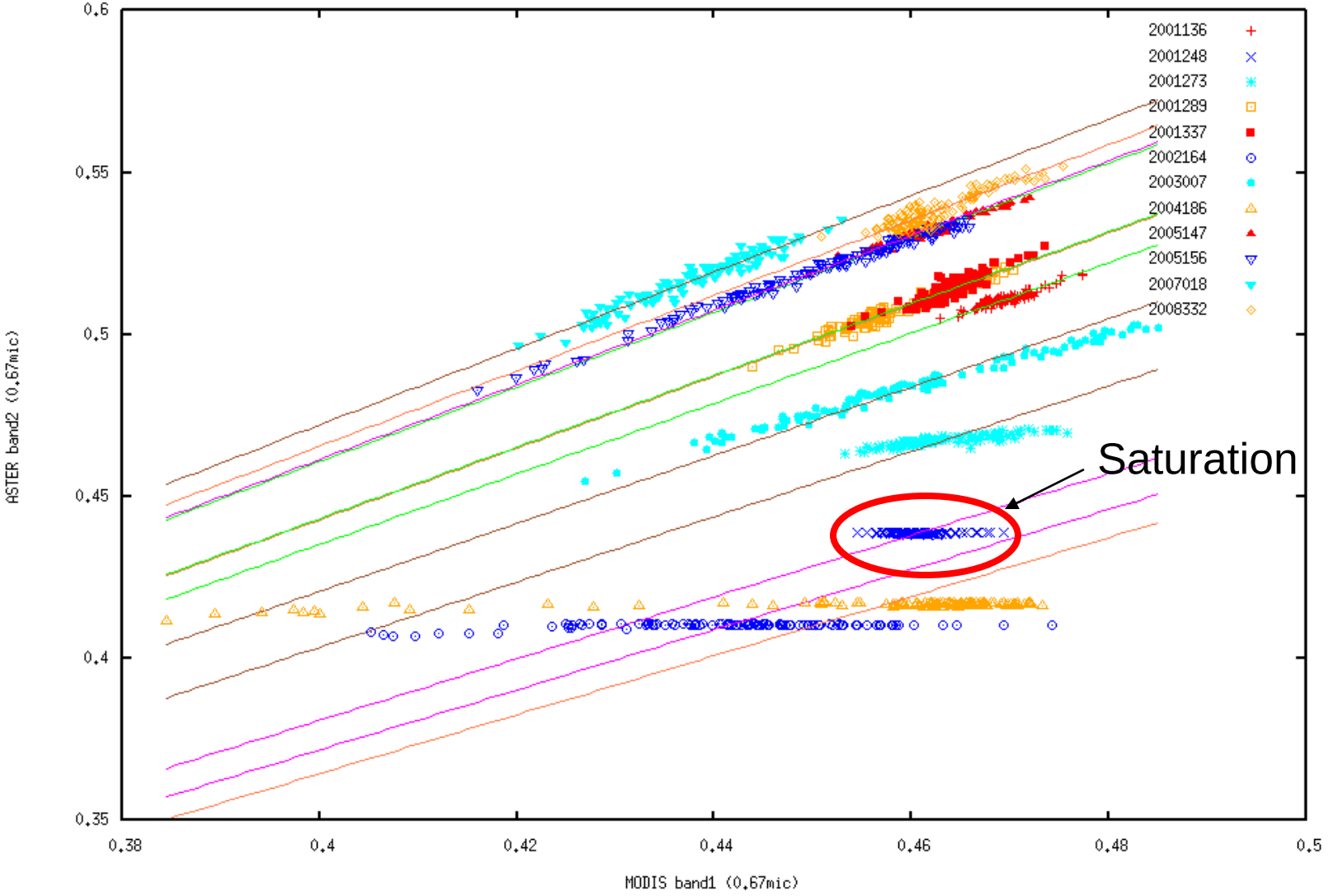
ASTER Calibration

Approach: Use coincident MODIS surface reflectance data (CMG) over desert site to atmospherically correct ASTER (mainly for water vapor, ozone, molecular scattering effect)

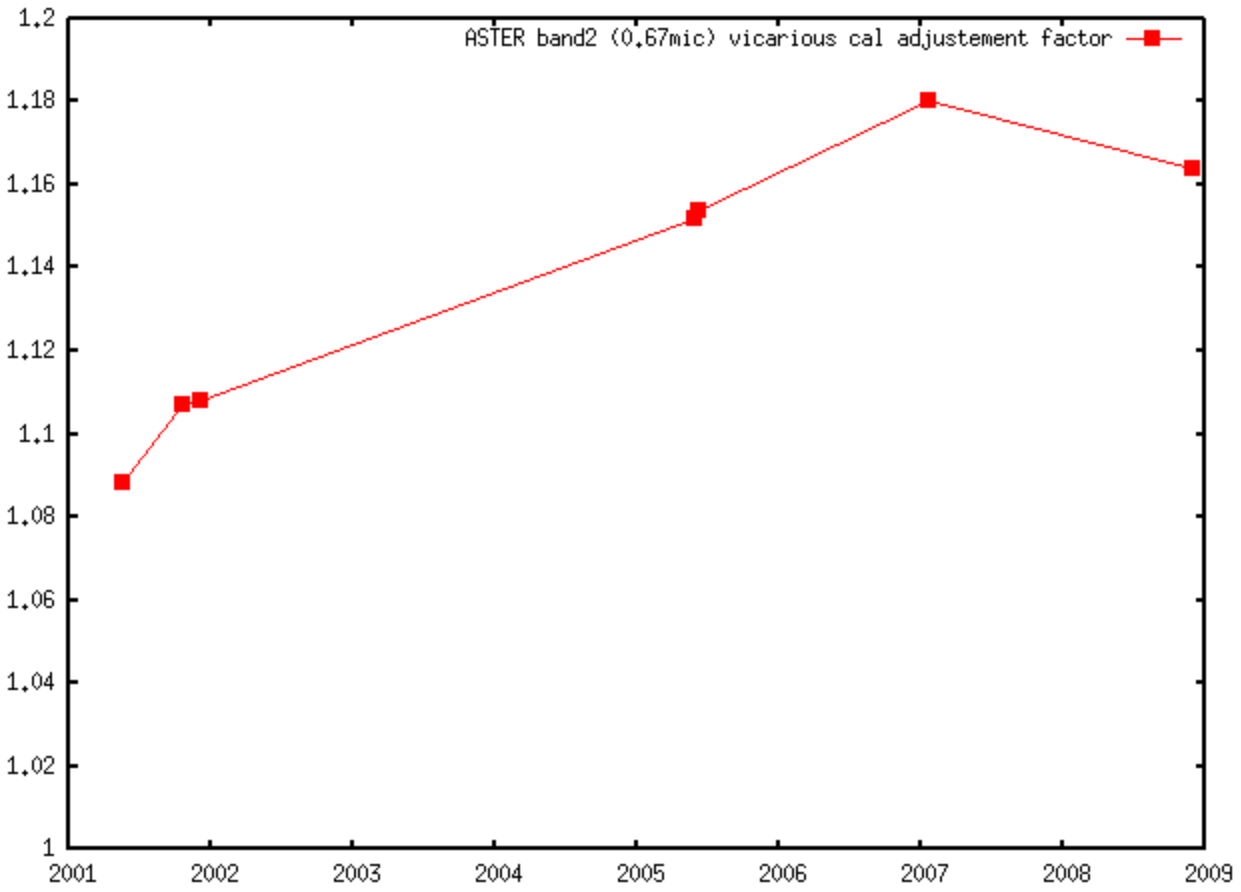


MODIS CMG

ASTER Results for band2 (0.67mic)



ASTER calibration trends for Red (excluding obvious saturation)



Using MODIS to develop global generalized BRDF correction and improved NDVI Time series

RED / NIR

NDVI

Directional reflectance

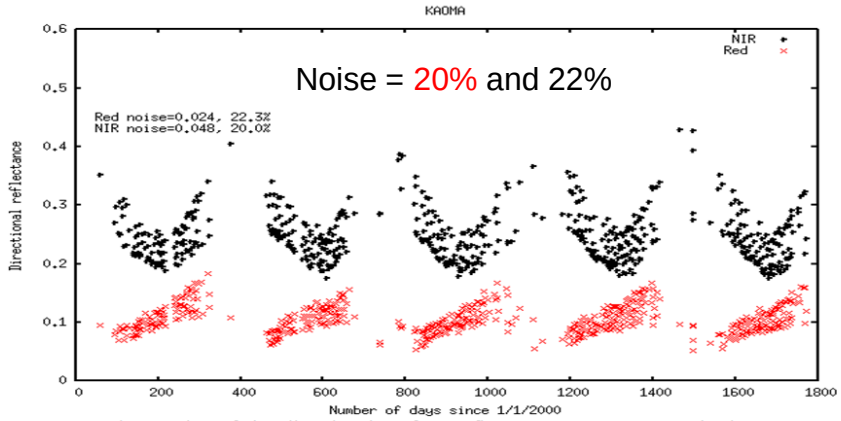


Figure 8a: Time series of the directional surface reflectance over a Savannah site, Kaoma (Zambia).

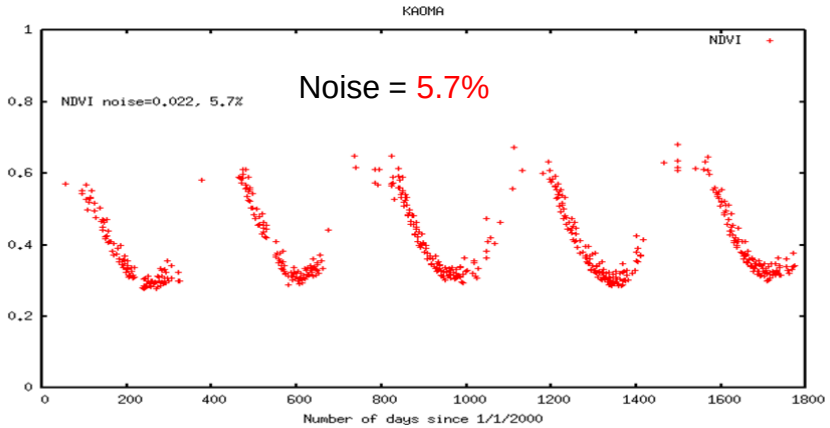


Figure 8c: Time series of the NDVI over a Savannah site, Kaoma (Zambia).

BRDF Normalization

Directional Normalized reflectance

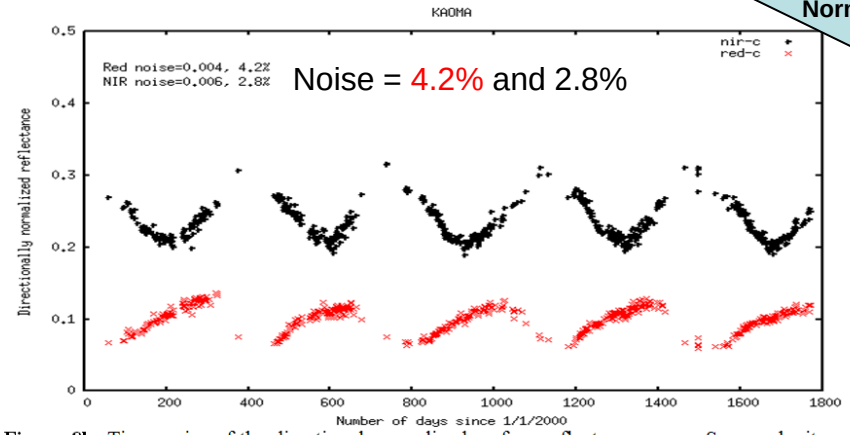


Figure 8b: Time series of the directional normalized surface reflectance over a Savannah site, Kaoma (Zambia). The approach used for correcting directional effect is described in [*Vermote et al.*, 2008]

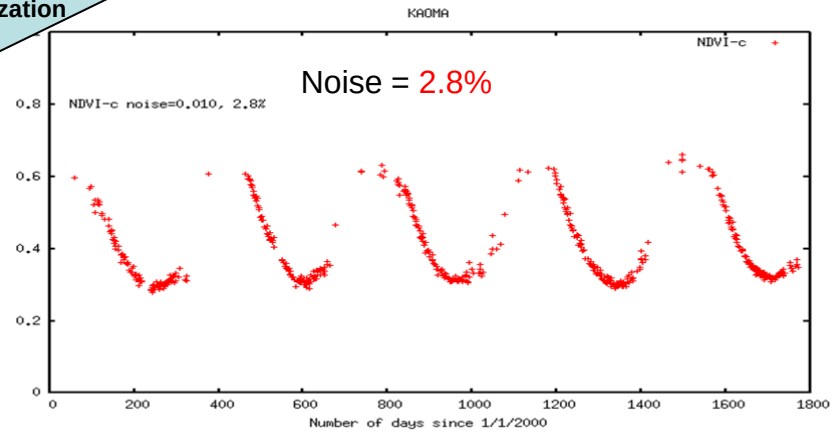


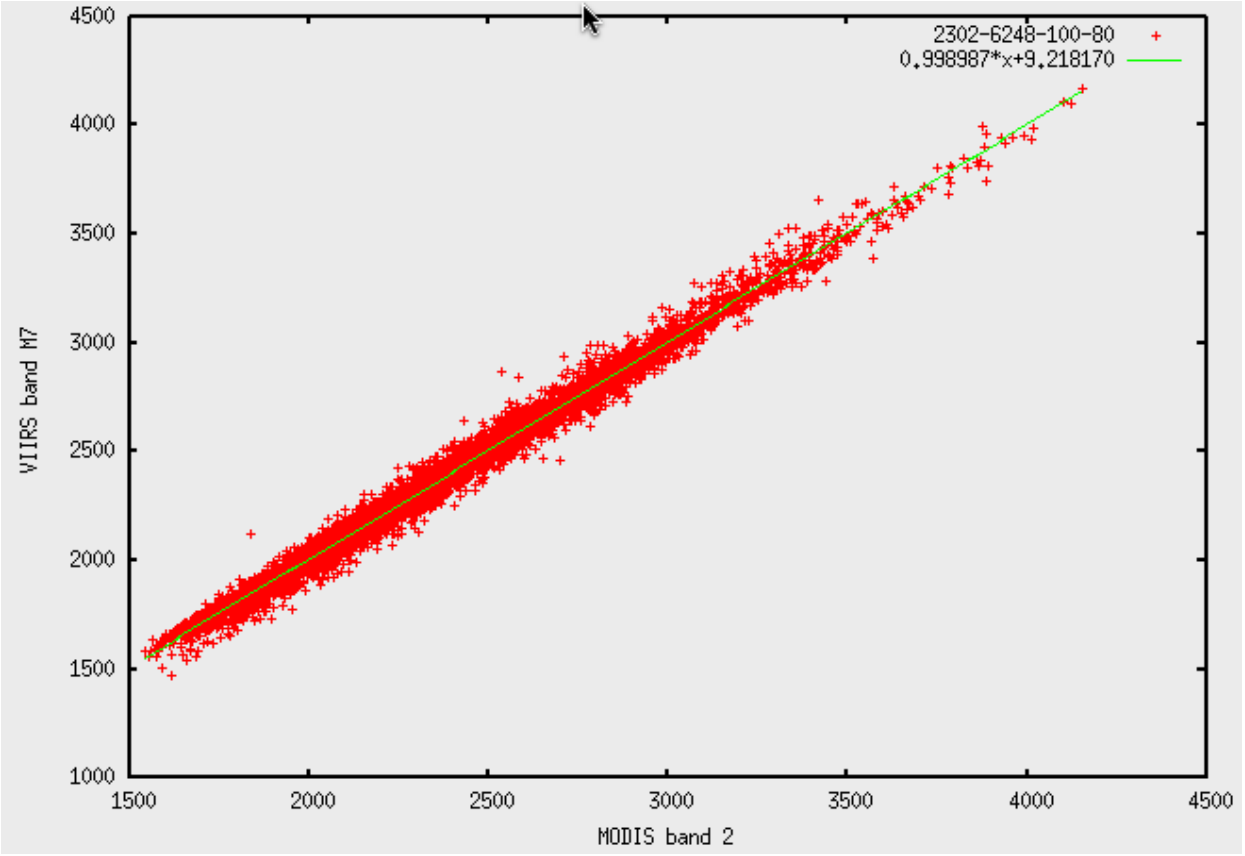
Figure 8d: Time series of the NDVI corrected for directional effect over a Savannah site, Kaoma (Zambia).

VIIRS SR

Aqua SR

Results for 3/06/2012

Site over Australia:
Data normalized for BRDF effect
(nadir, sun zenith angle= 45deg)
NIR bands: band 2 MODIS, band M7 VIIRS



Theoretical uncertainties for thr surface reflectance MODIS product

- **Validation and uncertainties estimates. Theoretical error budget, comprehensive evaluation.**

FOREST

Belterra

λ [nm]	ρ x10000	Clear	Average	Hazy
			Δρx10000	
470	120	52	51	52
550	375	49	55	64
645	240	52	59	65
870	2931	40	152	246
1240	3083	38	110	179
1650	1591	29	52	84
2130	480	41	28	42
NDVIx1000			ΔNDVI x1000	
849		30	34	40

SAVANNA

Skukuza

λ [nm]	ρ x10000	Clear	Average	Hazy
			Δρx10000	
470	400	52	52	53
550	636	52	58	64
645	800	53	62	67
870	2226	35	103	164
1240	2880	38	97	158
1650	2483	35	66	104
2130	1600	40	36	53
NDVIx1000			ΔNDVI x1000	
471		22	28	33

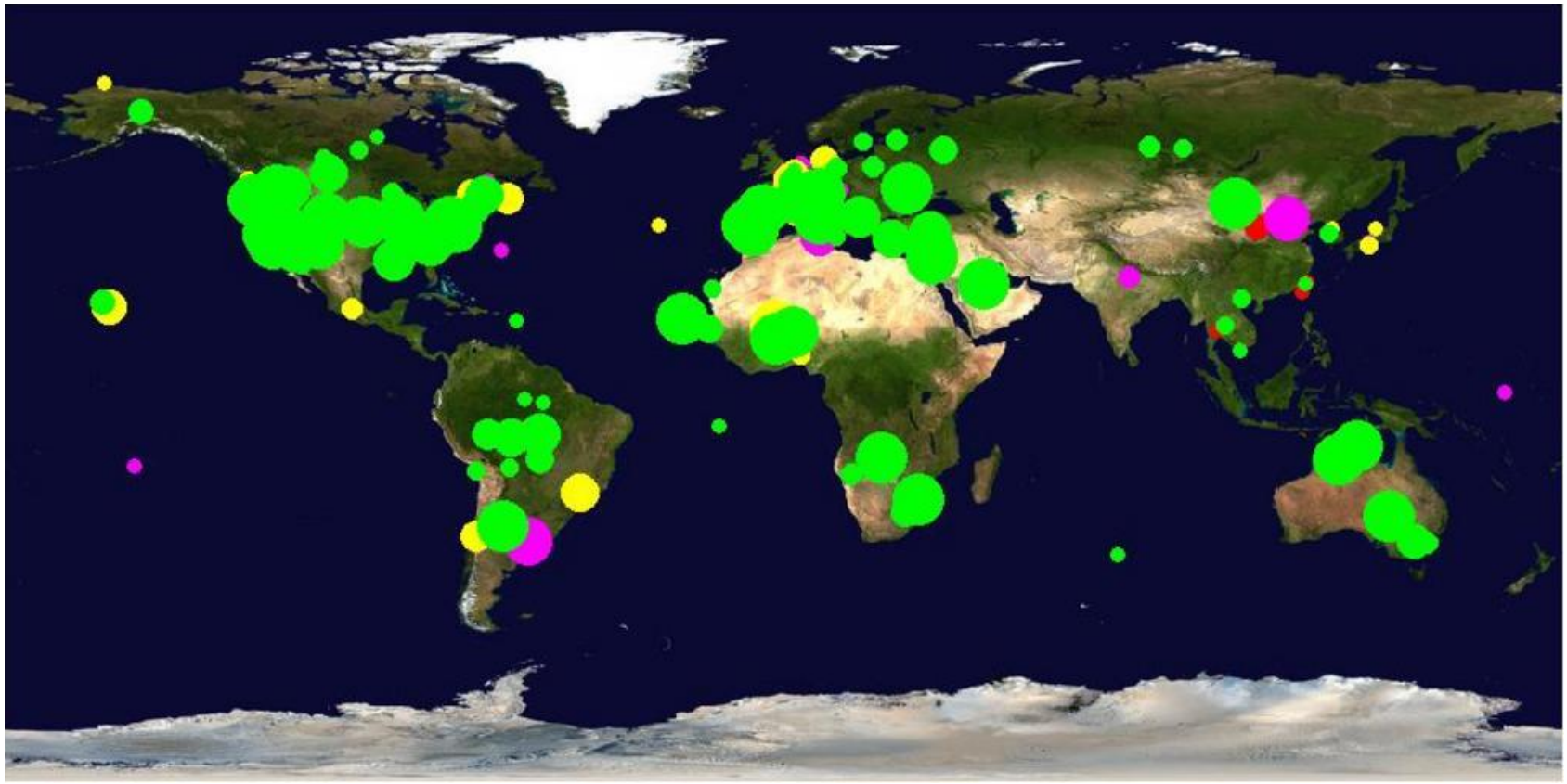
SEMI-ARID

Sevilleta

λ [nm]	ρ x10000	Clear	Average	Hazy
			Δρx10000	
470	700	51	53	55
550	1246	51	70	85
645	1400	57	74	85
870	2324	41	95	146
1240	2929	45	93	148
1650	3085	55	81	125
2130	2800	56	60	87
NDVIx1000			ΔNDVI x1000	
248		11	15	19

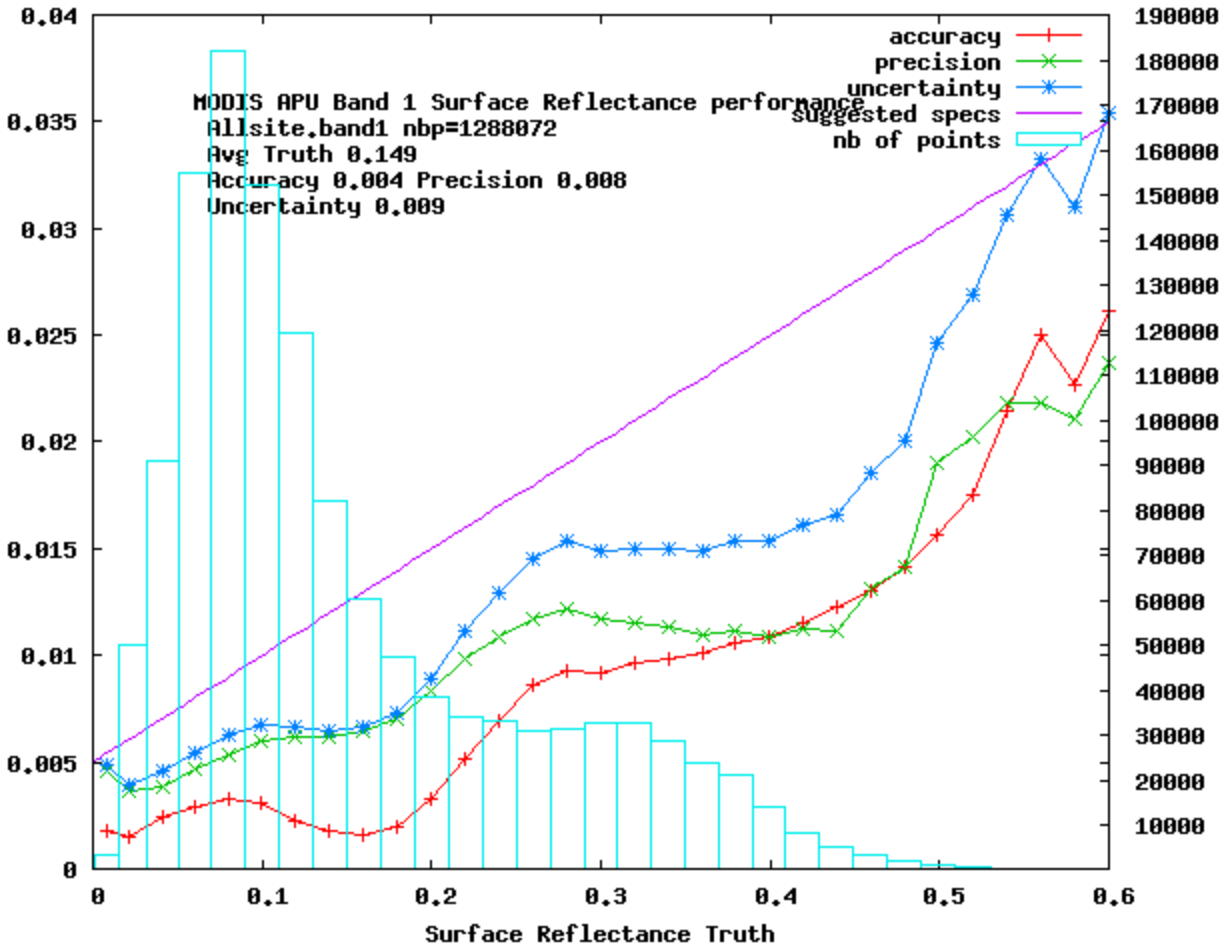
Error in ~0.5% in reflectance unit

Comprehensive analysis of performance using the AERONET network 2000-2007 Results (25542 cases)



Version 2 AERONET (i.e. with Background correction and spheroid)

Toward a quantitative assessment of performances (APU)



1,3 Millions 1 km pixels were analyzed for each band.

Red = Accuracy (mean bias)
Green = Precision (repeatability)
Blue = Uncertainty (quadatric sum of A and P)

On average well below magenta theoretical error bar

On going assessment of LEDAPS ETM+ surface reflectance product

- WELD (D. Roy) 120 acquisitions over 23 AERONET sites (CONUS)

  Junchang Ju, David P. Roy, Eric Vermote, Jeffrey Masek, Valeriy Kovalskyy, Continental-scale validation of MODIS-based and LEDAPS Landsat ETM+ atmospheric correction methods, **Remote Sensing of Environment** (2012), Available online 10 February 2012, ISSN 0034-4257, 10.1016/j.rse.2011.12.025.

- Google Earth Engine : Acquisitions over 120 AERONET sites (global) – In progress going for 300

- GFCC: Comparison with MODIS SR products

  – GLS 2000 demonstration

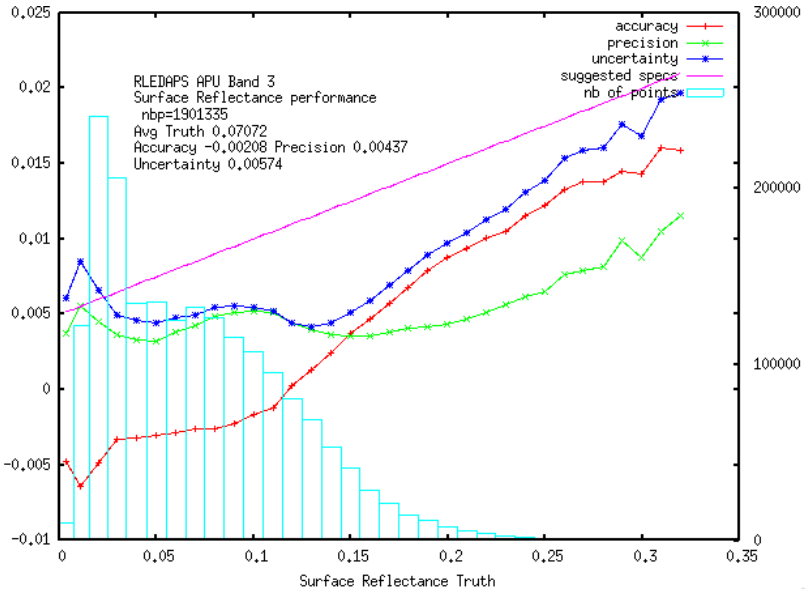
  Min Feng, Chengquan Huang, Saurabh Channan, Eric F. Vermote, Jeffrey G. Masek, John R. Townshend, Quality assessment of Landsat surface reflectance products using MODIS data, **Computers & Geosciences**, Volume 38, Issue 1, January 2012, Pages 9-22, ISSN 0098-3004, 10.1016.

  – GLS 2005 (TM and ETM+)

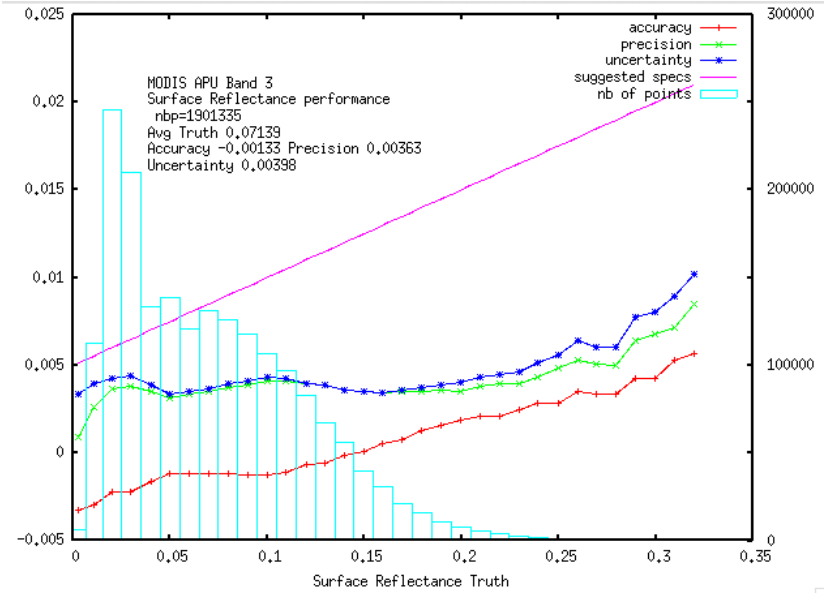
  Min Feng Joseph O. Sexton, Chengquan Huang, Jeffrey G. Masek, Eric F. Vermote, Feng Gao, Raghuram Narasimhan, Saurabh Channan, Robert E. Wolfe, John R. Townshend ,Global, long-term surface reflectance records from Landsat: a comparison of the Global Land Survey and MODIS surface reflectance datasets. **Remote Sensing of the Environment (in review)**

WELD/LEDAPS results (Red-band3)

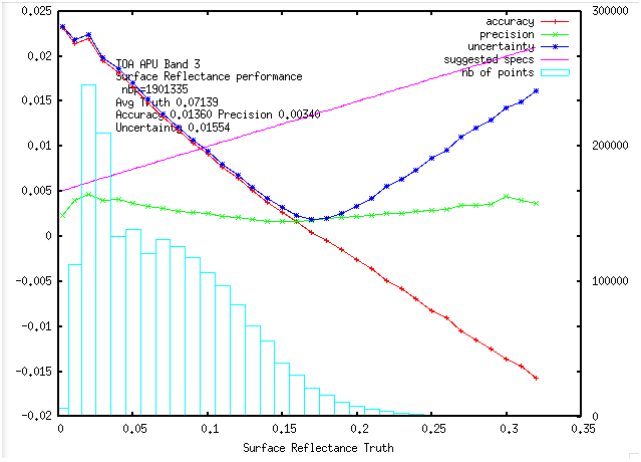
LEDAPS



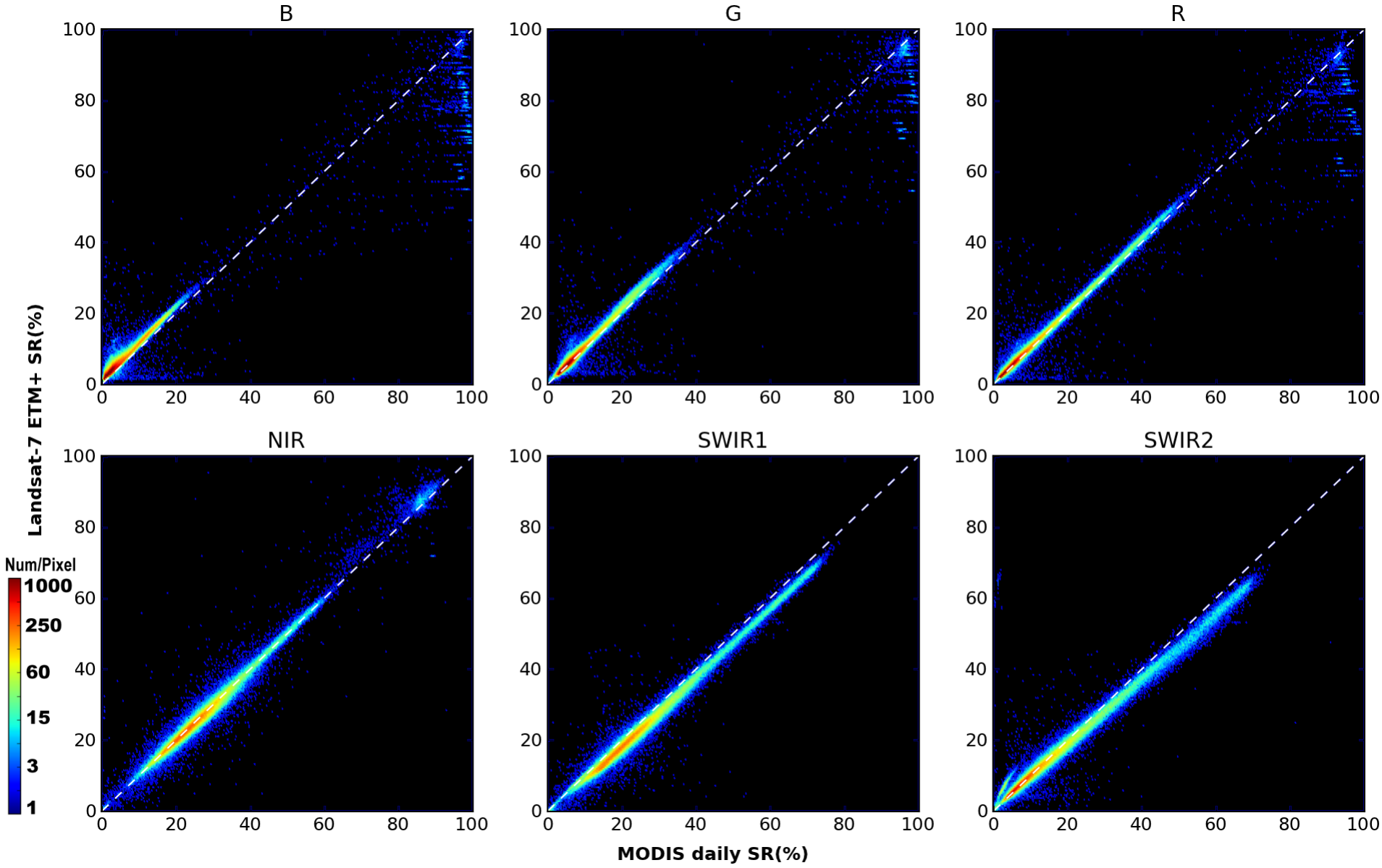
WELD uses MODIS aerosol



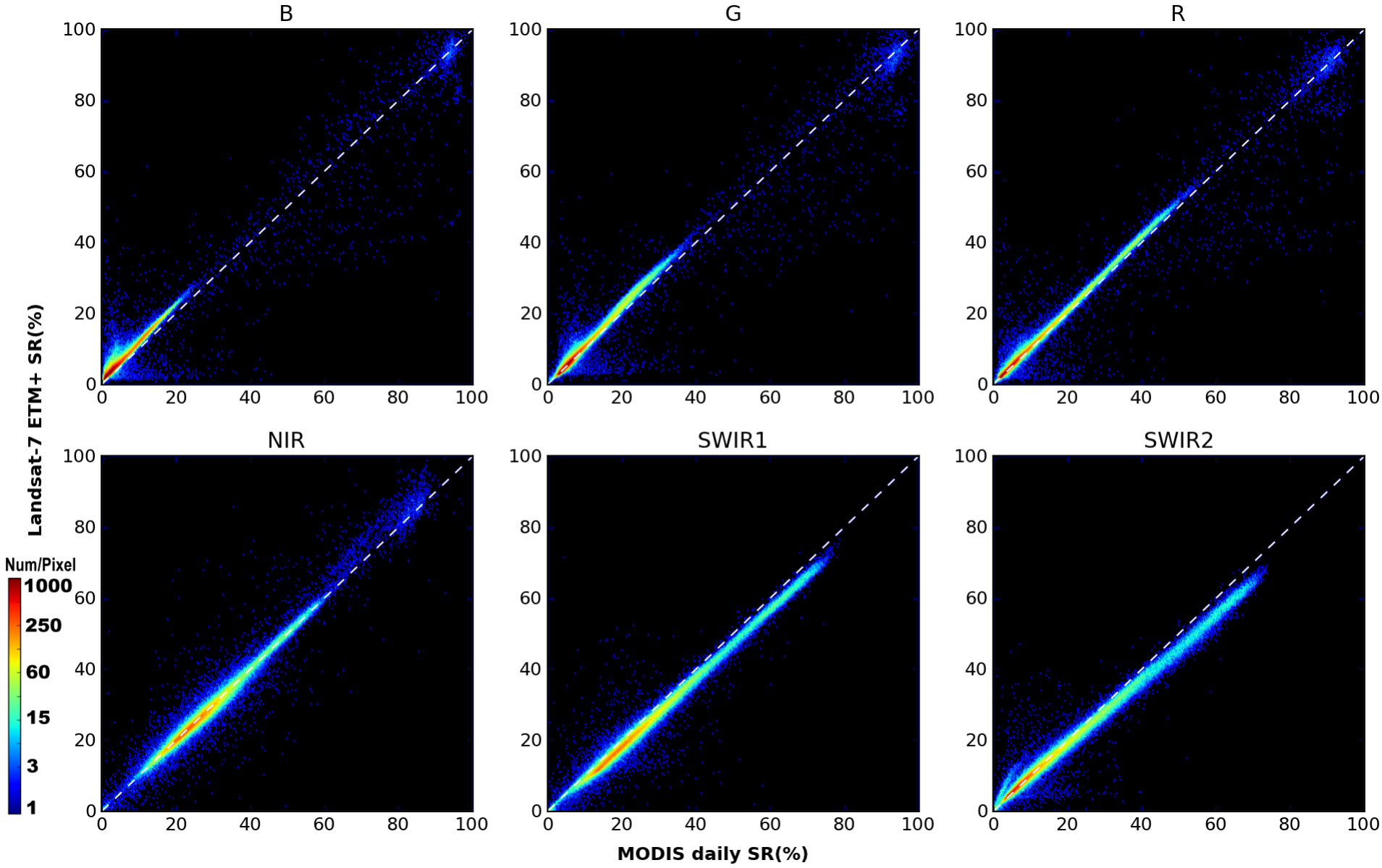
Top of the atmosphere



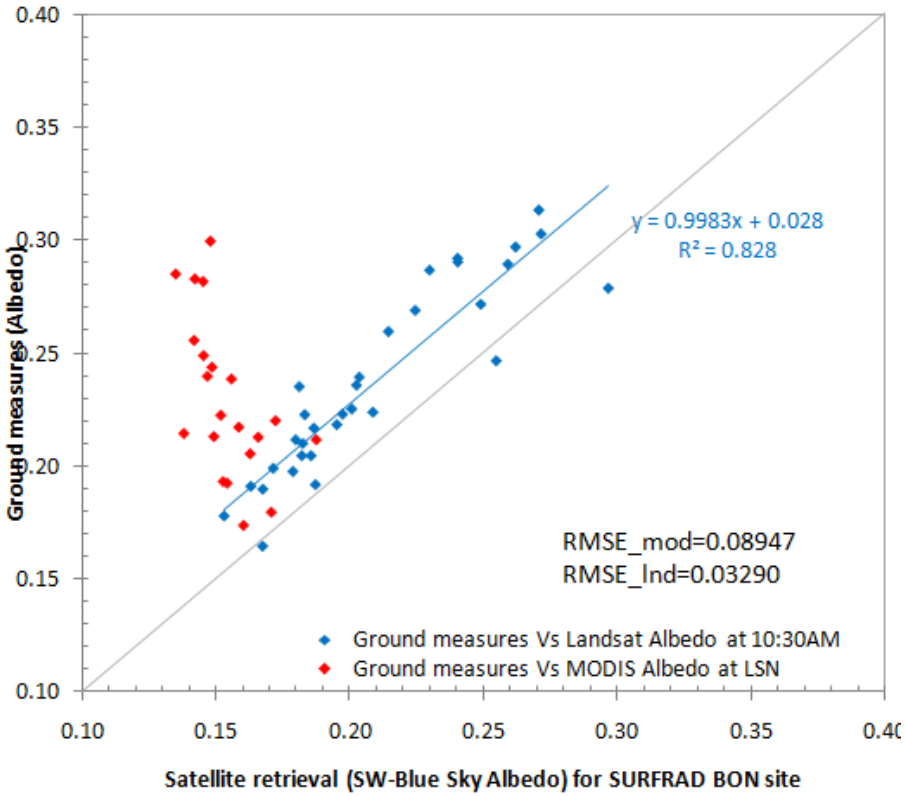
(A) GLS 2000 ETM+ vs. MODIS/Terra daily SR



(B) GLS 2005 ETM+ vs. MODIS/Terra daily SR



Landsat/LDCM spatial resolution offer better validation opportunity

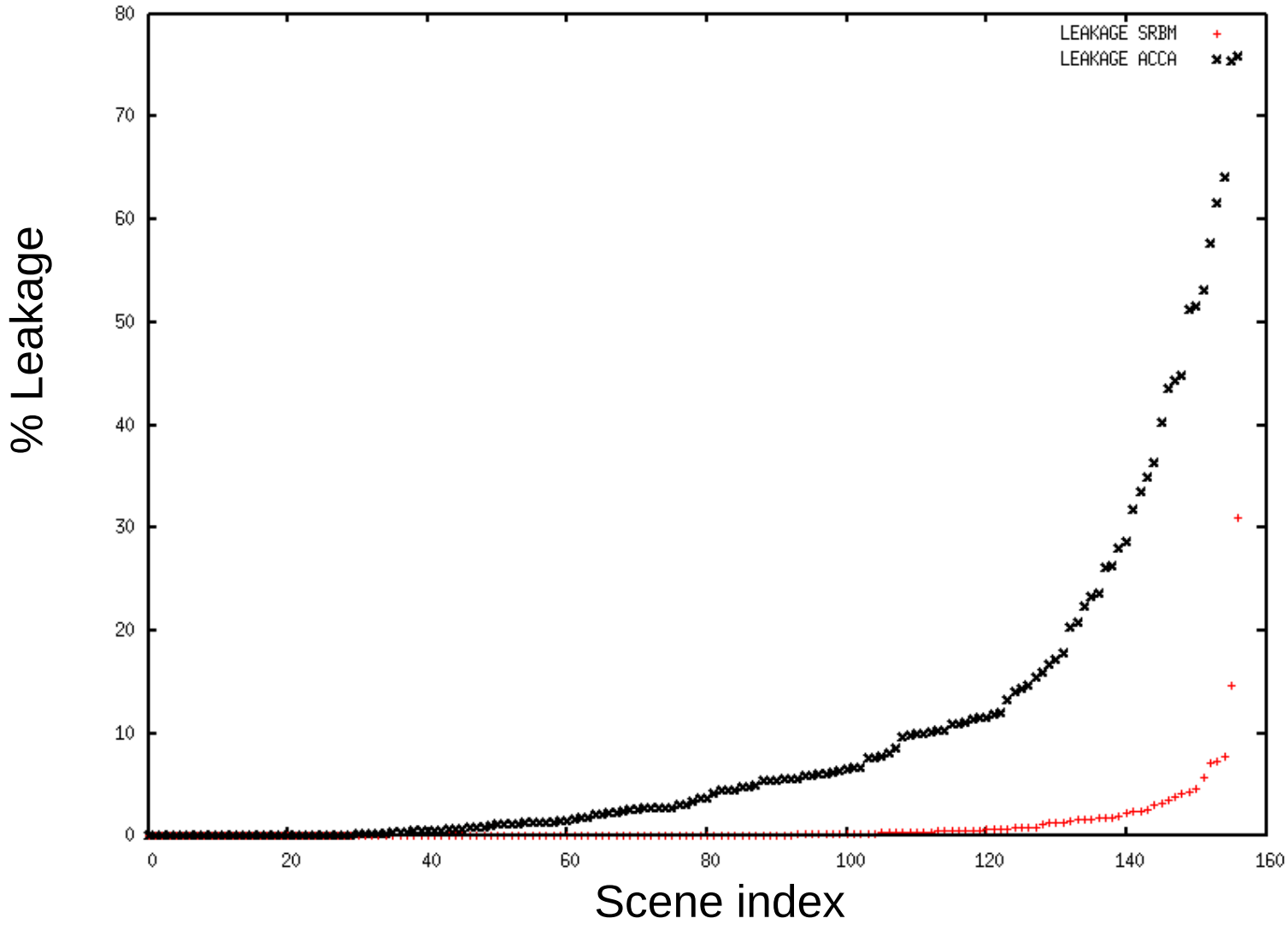


Courtesy of Feng Gao

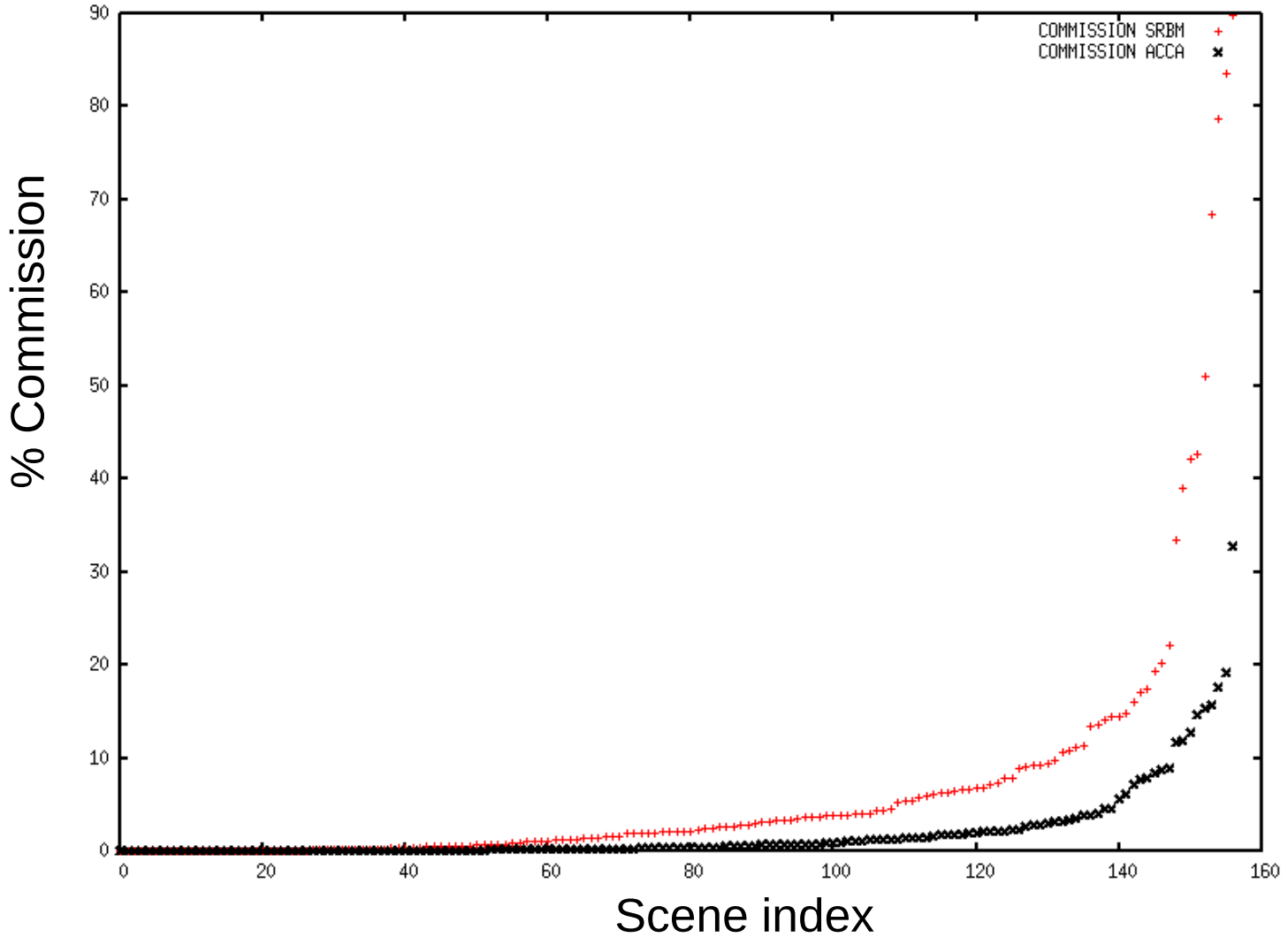
The Internal cloud/cloud shadow mask

- Performed in two stages (TOA first / SR second stage)
- Evaluated for 157 Landsat scenes covering a variety of conditions
- Cloud mask comparison
  - ACCA cloud mask
  - SRBM (Surface reflectance Based Mask): Internal cloud mask based on SR product
  - VCM :Truth Validation Cloud Mask (operator made)
- Metrics for cloud detection versus VCM
  - Rate of omission of cloud %: Leakage
  - Rate of commission of cloud % : False detection
- As far as leakage the internal cloud mask, SRBM, is superior to ACCA/ In term of commission ACCA has better performance than SRBM
- SRBM performance were confirmed by the comparison with Zhe et al. Cloud Mask over 143 scenes.
- LEDAPS SRB shadow algorithm needs improvements

LEAKAGE RATE comparison

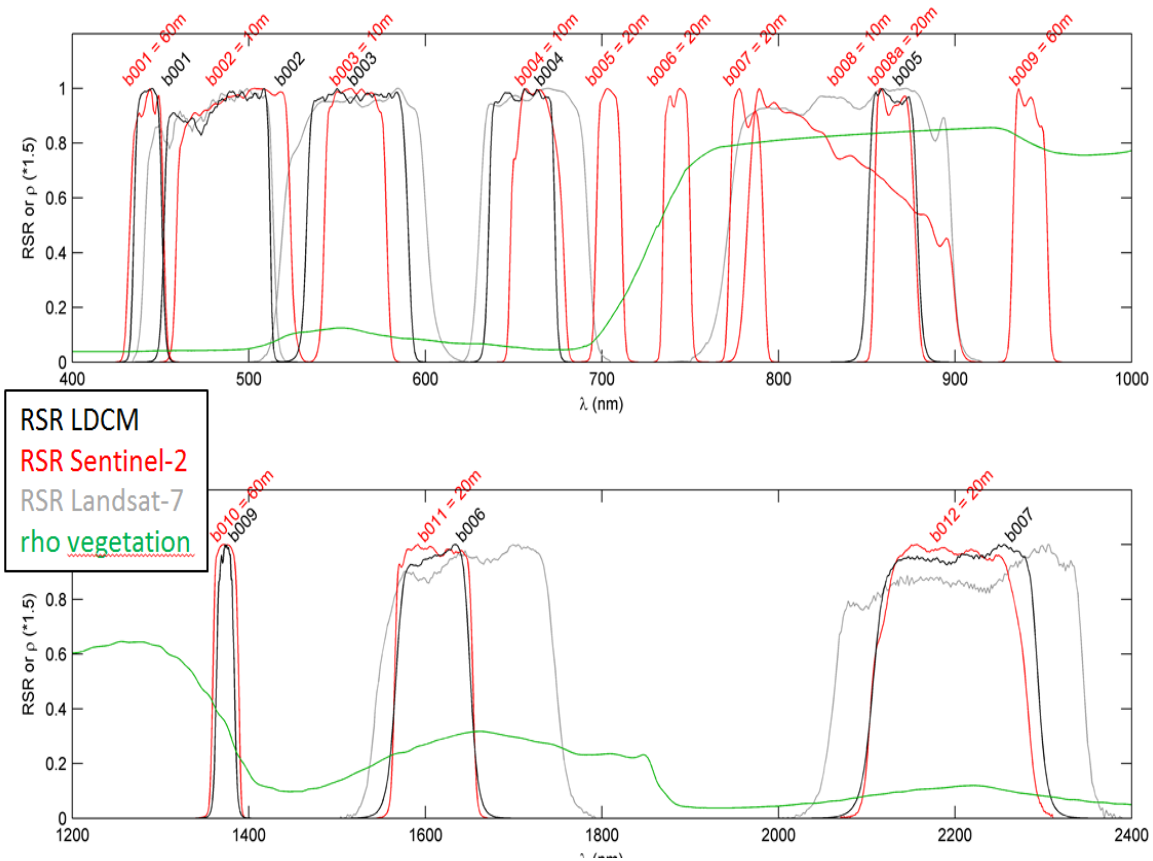


COMMISSION RATE Comparison



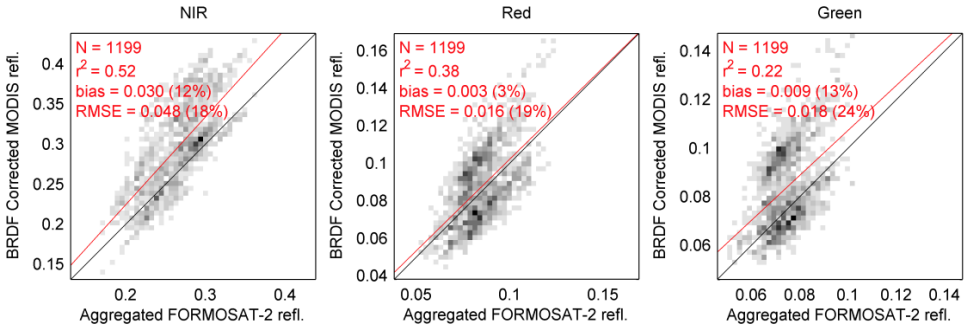
Sentinel 2

- Have similar spectral bands than LDCM/Landsat enabling the last version of aerosol retrieval and surface reflectance to be implemented

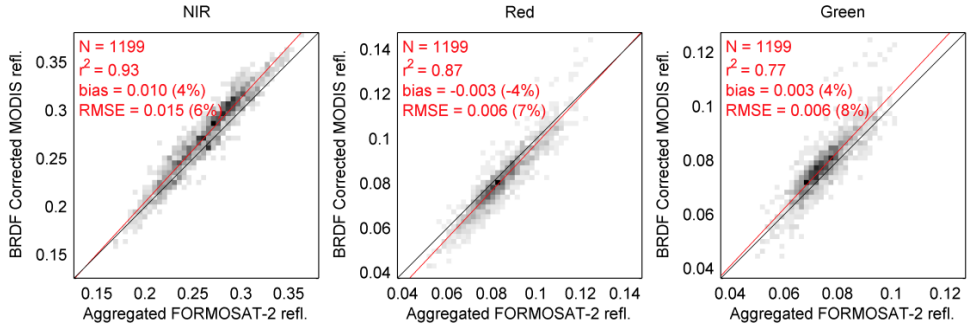


- Validation protocols are well defined and could be implemented
- Inter-comparison of products should be looked before launch (near coincidence, spectral differences etc…)
- Cf to Gutman/Masek presentation (today 4:30) about and LDCM-Sentinel-2 Data Merging Plans

Cross-comparison of MODIS SR with product derived using independent approach 1/2



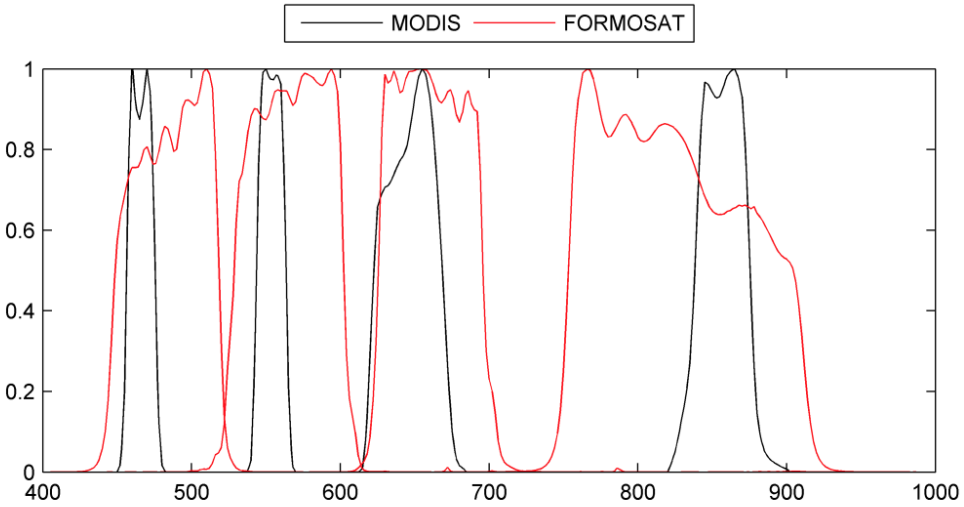
Comparison of aggregated FORMOSAT-2 reflectance and MODIS reflectance. No BRDF correction. Density function from light grey (minimum) to black (maximum); white = no data.



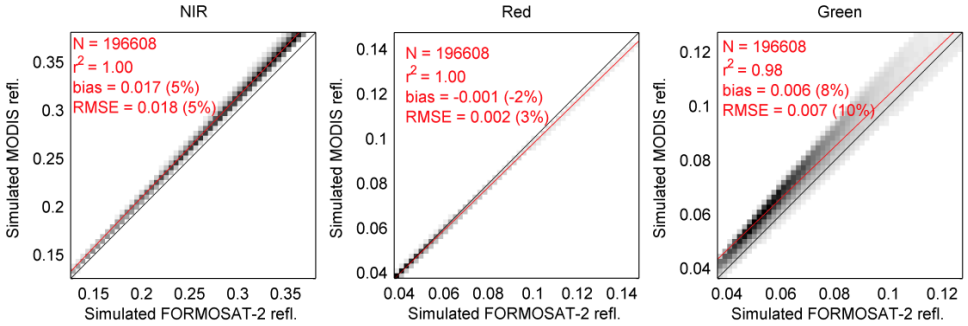
Comparison of aggregated FORMOSAT-2 reflectance and BRDF corrected MODIS reflectance. Corrections were performed with Vermote al. (2009) method using for each day of acquisition, the angular configuration of FORMOSAT-2 data.

From Claverie et al., 2013 (in preparation)

Cross-comparison of MODIS SR with product derived using independent approach 2/2



Spectral Bands of MODIS and FORMOSAT-2



Comparison of simulated FORMOSAT-2 and MODIS reflectance performed with PROSAIL model. The simulated dataset is the same as the one described in Baret et al. (2007).

Conclusions

- Surface reflectance algorithm is mature and pathway toward validation and automated QA is clearly identified.
- Algorithm is generic and tied to documented validated radiative transfer code enabling easier inter-comparison and fusion of products from different sensors (MODIS,VIIRS,AVHRR, LDCM, Landsat, Sentinel 2 …)